Pygmy dipole resonance

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Abstract. The pygmy dipole resonance (PDR) is a low-energy debris of the $1\hbar\omega$ $E1$-strength which is pushed by an isovector residual interaction to higher energies to form the giant dipole resonance. It exhausts about 1% of the EWSR below the particle threshold. High energy resolution experiments performed during the last decade reveal fine structure of the PDR in many nuclei. We report on the studies of the PDR fine structure performed within the Quasiparticle-Phonon model. Excited states are described by a wave function which includes one-, two-, and three-phonon configurations, i.e. the configuration space in calculations below the threshold is almost complete. We discuss also some particular features of the PDR excitation in different nuclear reactions.

A low-energy dipole strength below the threshold has been observed for the first time in experiments with tagged photons (see, e.g., [1]) in the late 70-ies. It was observed as a kind of a bump on top of the tail of the giant dipole resonance and received the name of the "pygmy dipole resonance" (PDR). Theoretical calculations of those days also reported substructures at low energies [2]. With a new generation of germanium detectors it became possible in the late 90-ies to resolve the fine structure of the PDR establishing that many dozens of 1^- states are excited in the nuclear resonance fluorescence (NRF) experiments to form the PDR [3, 4]. During the last decade the properties of the PDR have been studied within many different theoretical approaches. In my talk I limit the presentation by only the results obtained within the quasiparticle phonon model (QPM) [5].

From the theoretical point of view, the PDR may be considered as a low-energy debris of the $1\hbar\omega$ $E1$-strength which is pushed to higher energies by an isovector residual interaction forming the giant dipole resonance (GDR) (see figure 1). As figure 2 demonstrates, while many two-quasiparticle configurations contribute coherently to the E1 transition matrix element of a state belonging to the GDR, we deal with a destructive interference in the case of a PDR state.

The process of the strength fragmentation in the PDR energy region is demonstrated in figure 3 for ^{136}Xe. The major part of the E1 strength below the threshold is carried by a few QRPA (or one-phonon) states (figure 3a). These states are coupled to more complex configurations. Theoretically, to describe this process we write the wave function of excited states as a composition of one-, two-, etc. phonon configurations and diagonalize the model Hamiltonian to obtain the eigenstates. Calculation performed on the basis of one- and two-phonon configurations is presented in figure 3b. In this calculation each 1^- state carries only a small fraction of one-phonon configurations and accordingly, its B(E1) value is much smaller than in figure 3a. At the same time, the total B(E1) strength does not change much for the PDR energy region. The fragmentation process continues when three-phonon configurations are added to the wave function (figure 3c). One should keep in mind that the density of four-, five-,

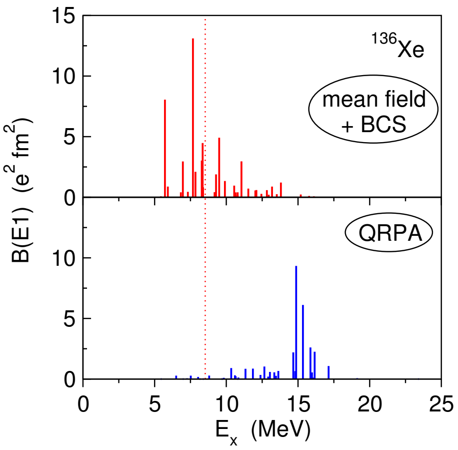

Figure 1. E1-strength distribution in ^{136}Xe calculated in the mean field and QRPA approximations. Dashed line shows $1\hbar\omega$ energy.

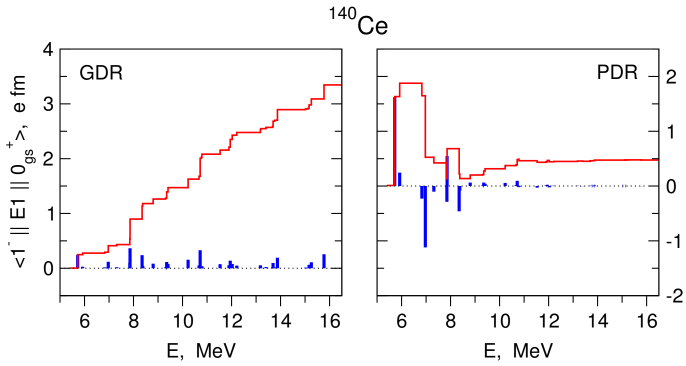

Figure 2. Running sum of the E1 transition matrix element for a state belonging to the GDR and PDR. Vertical lines present contribution of different two-quasiparticle configurations to the matrix element.

etc. phonon configurations is still very low below the threshold. It means that calculation in figure 3c is performed on almost complete basis of states for this energy region.

In addition to 1^- states, 1^+ states are also excited by an electromagnetic probe below the threshold. The later are either isoscalar 1^+ states or the ones belonging to the tail of the M1 resonance (see figure 4).

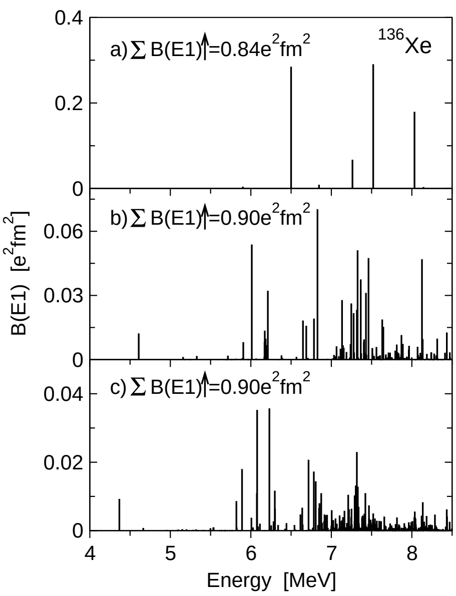

Figure 3. Fragmentation of the PDR in ^{136}Xe. Calculations are performed: a) within the QRPA, and with coupling to b) two- and c) two- and three-phonon configurations.

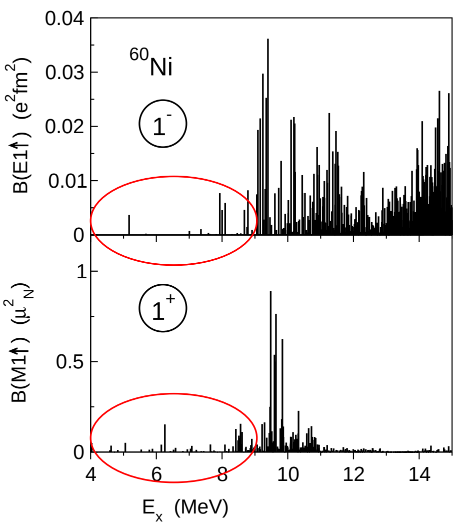

Figure 4. Fragmentation of the E1 and M1 strength in ^{60}Ni. Oval marks the energy interval which is typically covered in NRF experiments.

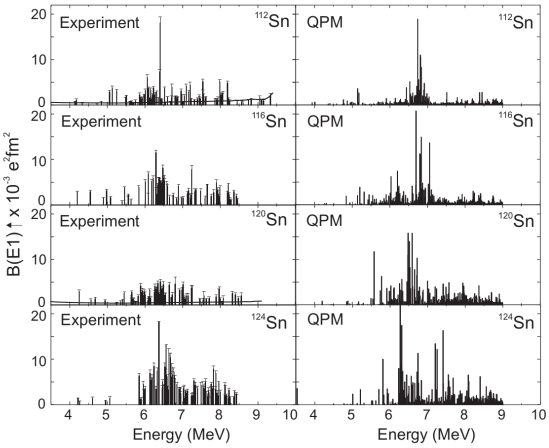

Figure 5. Fragmentation of the PDR in Sn isotopes.

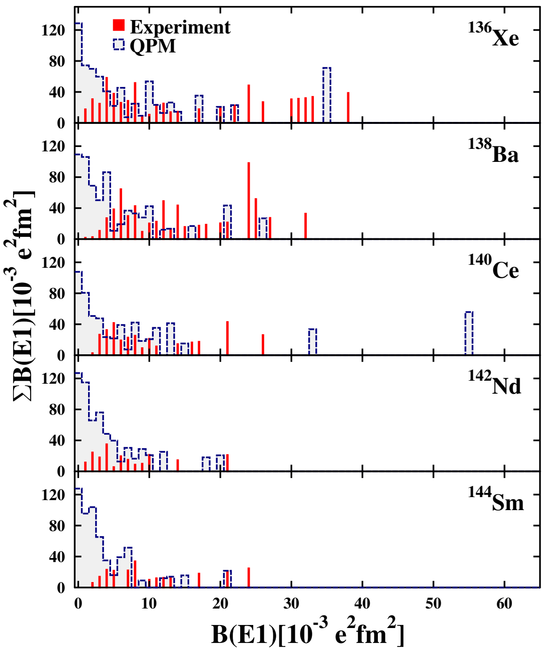

Figure 6. Fragmentation in the experimentally observed distribution and within the QPM for the N = 82 isotones.

The QPM calculations of the PDR have been performed for nuclei belonging to different parts of the nuclei chart: Cr-Fe-Ni [6, 7, 8], Zr-Mo [9] regions, Sn isotopes [4, 10, 11], N=82 isotones [12], and Pb isotopes [13]. The model describes rather well fragmentation of the E1 strength in the PDR region (see, e.g., figures 5 and 6) when almost complete basis of complex configurations is employed. In addition to many observed 1^- states it predicts many more weak 1^- states below detection limit (see left part of figure 6).

The PDR has been recently studied in $(\alpha, \alpha'\gamma)$ reaction [11, 14]. A good correspondence between the levels observed in this reaction with the (γ, γ') data has been established for the low energy part of the PDR. But no 1^- levels have been detected in the $(\alpha, \alpha'\gamma)$ reaction at higher excitation energy. Calculation in figure 7 also predicts that excitation of the low energy part of the PDR by the isoscalar r^3Y_1 external field which mimics (α, α') reaction, is enhanced in comparison to the excitation by the electromagnetic field. Analysis of transition densities indicate that their tails out of nucleus are responsible for this enhancement.

The PDR has been also observed in the (p, p') reaction at small scattering angles [15]. To extract information on 1^- states in the energy region of overlapping levels the multipole decomposition analysis (MDA) has been performed. The spectrum has been split into energy bins of about 100 keV and the cross section behaviour in each of them has been fit assuming contribution from 1^-, 1^+, and 2^+ levels (see figure 8 top). For 1^- levels cross sections have been calculated with the PDR and GDR wave functions. It has been found that the best χ^2 fit for the low energy part of the spectra is obtained with the PDR wave function while at higher energies the GDR wave function gives better results (see figure 8 bottom).

A new direction in the PDR studies concerns its decay properties. In analysis of the NRF spectra branching ratios to low-lying states are often neglected. Nevertheless, decays into them have been observed (see, e.g., [7]).This type of studies allows not only to correct extracted from

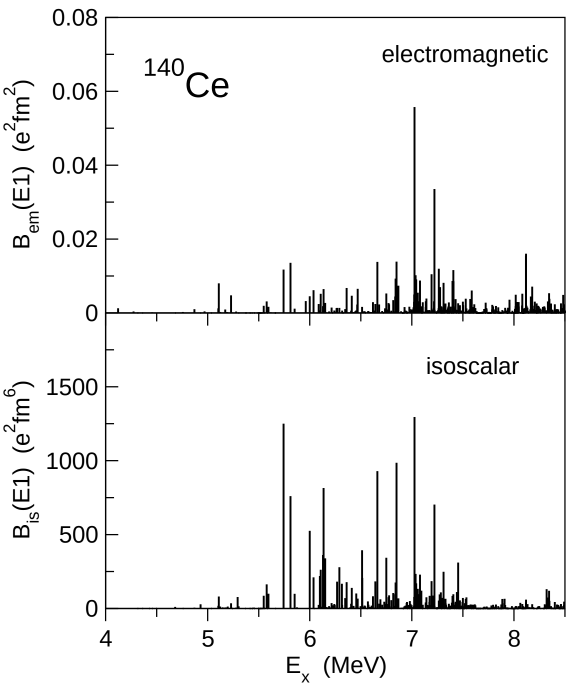

Figure 7. Electromagnetic and isoscalar response for 1^- states in ^{140}Ce.

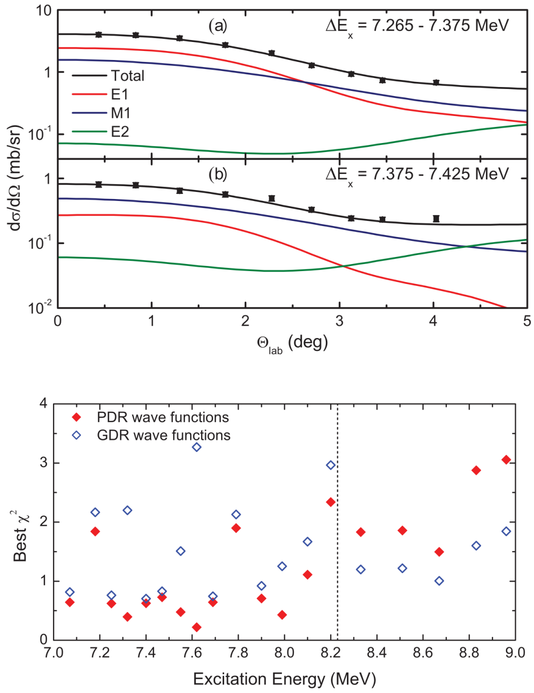

Figure 8. Examples of the MDA fits for two adjacent energy bins (top) and best χ^2 values in the MDA using either PDR- or GDR-type angular distributions for excitation energies $E_x = 7$ to 9 MeV (bottom).

NRF data B(E1) value but also investigate coupling of doorway 1^- states to some particular complex configurations.

Acknowledgments

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References

[1] Laszewski R M 1986 *Phys. Rev.* C **34** 1114; Laszewski R M and Axel P 1979 *Phys. Rev.* C **19** 342
[2] Soloviev V G, Stoyanov Ch and Voronov V V 1978 *Nucl. Phys.* A **304** 503
[3] Herzberg R-D *et al* 1997 *Phys. Lett.* B **390** 49
[4] Govaert K *et al* 1998 *Phys. Rev.* C **57** 2229
[5] Soloviev V G 1992 *Theory of Atomic Nuclei, Quasiparticles, and Phonons* (IOP, London)
[6] Bauwens F *et al* 2000 *Phys. Rev.* C **62** 024302
[7] Scheck M *et al* 2013 *Phys. Rev.* C **87** 051304; Scheck M *et al* 2013 *Phys. Rev.* C **88** 044304
[8] Pai H *et al* 2013 *Phys. Rev.* C **88** 054316
[9] Romig C *et al* 2013 *Phys. Rev.* C **88** 044331
[10] Özel B *et al* 2009 *arXiv:0901.2443*
[11] Endres J *et al* 2010 *Phys. Rev. Lett.* **105** 212503; Endres J *et al* 2012 *Phys. Rev.* C **85** 064331
[12] Savran D *et al* 2008 *Phys. Rev. Lett.* **100** 232501; Savran D *et al* 2011 *Phys. Rev.* C **84** 024326
[13] Enders J *et al* 2003 *Nucl. Phys.* A **724** 243
[14] Savran D *et al* 2006 *Phys. Rev. Lett.* **97** 172502
[15] Tamii A *et al* 2011 *Phys. Rev. Lett.* **107** 062502; Poltoratska I *et al* 2012 *Phys. Rev.* C **85** 041304